RESULTS OF THE FIRST GPS MEASUREMENT CAMPAIGN FOR THE DETERMINATION OF ABSOLUTE VERTICAL AND HORIZONTAL DEFORMATIONS IN THE MAIN AND OLD CITY OF GDAÑSK

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The paper presents the results of the first GPS measurement campaign, conducted in December 2006, on a network of fundamental altitude points, situated in the Main and Old City of Gdañsk.

Key words:
GPS, altitude geodetic matrix

1. INTRODUCTION

"A Technical Project of Precise GPS Measurements and Scientific Research in order to determine precisely the vertical and horizontal deformations in the main and Old City of Gdañsk" (Baryła R. et al., 2005) was developed in 2005. The Technical Project of GPS precise measurements provides for sixteen altitude points:

- four reference points,
- twelve check points.

The precise GPS satellite measurements were carried out with the use of measurement equipment manufactured by Ashtech and accessories (cables, electric cells). Two-frequency, twelve-channel GPS receivers:

1) Z-Xtreme, with ASH701975.01A aerial – 7 pcs,
2) Z-XII, with ASH700228.D aerial – 3 pcs

were used for the measurements.
Methods of forced centring of GPS aerials were applied at the reference and check points. GPS aerial centring was carried out by substages fixed directly to the point heads (Fig. 1), the aerials altitude in relation to the three altitude points situated in each of the heads was measured with a slide calliper within an accuracy of 0.05 mm. Centring of GPS aerials at the check points was carried out with the appropriate construction of 2.22 m long poles (Fig. 2), placed directly on the ground altitude points and stabilised with geodetic tripods equipped with additional adjustable heads (Fig. 3). The length of each pole was measured (calibrated) with high accuracy (0.05 mm); it determined the altitude of the main point of the GPS aerial above the altitude point.

Fig. 1. Fixing the GPS aerial on a reference point.

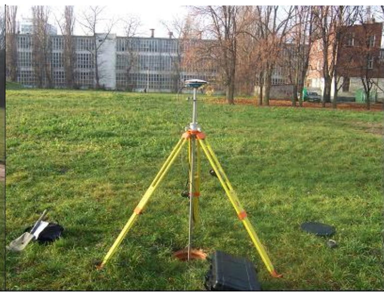

Fig. 2. Positioning the GPS aerial on a check point.

Fig. 3. Equipping a tripod with a pole-stabilising adjustable head.

2. THE MEASUREMENT PROCEDURE

Ten GPS receivers were used in the measurements. In order to verify the correctness of the measurement procedures, four twelve-hour measurement sessions were conducted, thereby obtaining 48-hour measurement sessions at the reference points and 24-hour measurement sessions at check points. GPS observations were carried out on: 01, 02, 03 and 04 December 2006.

The following measurement parameters were adopted for the measurement campaign:

- measurement interval: 10 s,
- EMA: 10º,
- maximum PDOP value: 6
- duration of the measurement session: 12 hours.

Due to different structure of reference points and check points, different measurement procedures had to be followed.

2.1. Measurement procedure at the reference points

Before the GPS measurements at a reference point were started, the observer should carefully check the condition of the mark head and perform the following activities:

- screw the fixing screw into the mark head (Fig. 4),
- fix and level the substage (Fig. 5),
- place the GPS aerial in the substage,
- connect the aerial with the receiver, start the receiver,
- enter (check) the observational parameters of the GPS receiver,
- measure with a calliper the altitude of the GPS aerial in relation to the three reference points, situated on the reference mark head (Fig. 6).

The procedure of a GPS aerial altitude measurement with a calliper should be repeated every three hours.

Fig. 4. The screw fastening substage in the reference point mark head.

Fig. 5. Fastening and forced centring of the substage in the reference point mark head.

Fig. 6. Measurement of a GPS aerial altitude with a calliper in relation to one of the three reference points, situated on the reference mark head.

2.2. Measurement procedure at the check points

Before the GPS measurements at a check point were started, the following activities should have been performed:

- remove the drain cover and the rubber benchmark shield (Fig. 7), followed by careful examination of the check point mark condition,
- place a tripod over the point,
- place a pole in the tripod's adjustable head and leading the sleeve, situated on the bottom part of the pole, onto the benchmark (Fig. 8),
- screw the GPS aerial to the pole (Fig. 9), direct the aerial to the north,
- fasten the screws of the pole-fixing adjustable head, put the libella (Fig. 10) at the upper position with a tripod, fix the tripod legs in the ground,
- connect the aerial to the GPS receiver,

- **precisely level the spirit levels (Fig. 11) with screws of the adjustable sleeve (Fig. 12),**
- **start the GPS receiver,**
- **enter (check) observation parameters of the GPS receiver.**

In the course of the GPS observation the correctness of the position of bubbles in the spirit level was checked every hour. If the position was found to have changed, the levelling was corrected and the fact was recorded in the observation diary, stating the time, direction and value of the shift in position.

Fig. 7. Uncovered drain of the check point mark. The drain cover and the rubber shield of the benchmark visible on the side.

Fig. 8. Placing a pole on the benchmark. The benchmark is inside the sleeve situated at the pole end.

Fig. 9. Fastening a GPS aerial in the upper part of the pole.

Fig. 10. A set of libels enabling the precise centring of the GPS aerial.

Fig.11. An adjustable head, integrated with the tripod, enabling precisely vertical positioning of the pole (putting the bubbles of spirit levels at the upper position).

2.3. Summary of the GPS measuring campaign

The GPS measuring campaign in the Main and Old City of Gdañsk and at the sites of stabilisation of reference points was conducted according to the schedule of measurement sessions. No damage was found at the reference point or check point marks. At check point 11 the drain well cover was found missing, and the drain itself was filled with earth for safety reasons.

The observers faced additional obstacles while performing observations at check points 6 and 7. In the vicinity of check point 6 there was a metal information board (Fig. 12), and at check point 7 there was a steel container placed there for the apartment renovation that was being done at the time, which made the correct positioning of the GPS aerial difficult (Fig. nr 13).

Other than that, no problems were encountered during the campaign, either from the inhabitants of Gdañsk or from the law enforcement bodies.

Fig.12. An obstacle (a metal information board) hampering GPS satellite signal reception at check point 6.

Fig.13. An obstacle (a steel container) hampering the correct positioning of the GPS aerial over check point 7.

3. ANALYSIS OF THE OBSERVATION RESULTS

The data gathered during the observation in the form of observation data sets in the Ashtech format: B, E, S, were converted to the RINEX format. Calculations were performed with BERNESE GPS SOFTWARE v. 5.0 (rel. 15-DEC-06) (Hugentobler U., 2001).

An analysis of the observation data showed that between 90 and 97% of all the available information was recorded during the measurement. Between 67 and 92% of all the available information was gathered at the check points. At reference point II 70% of the information was registered on the first day due to hardware problems, and at check point 7, 70 and 67% of information, respectively, was recorded due to numerous natural screens around the measurement site (Fig. 14).

Fig. 14. Natural screens, hampering the GPS satellite signal reception and situated around check point 7.

Rys.15. Connection of the reference points with the permanent stations of the IGS network: BOR1, LAMA, POTS.

3.1. Finding the coordinates of the reference points

Coordinates for each reference point were found in relation to three permanent stations of the IGS (*International GNSS Service*) network, based on four 12-hour observation sessions conducted from 1.12.2006 to 4.12.2006. The IGS stations used for the connection were: LAMA, BOR1, POTS (Fig. 15, Table 1). The coordinates of the reference points were determined in the ITRF 2005 system (the international system of global coordinates, currently used in precise GPS calculations). Special attention was paid to the problem of troposphere modelling as this parameter is currently thought to have the greatest effect on the precision of determination of the station altitude (the correlation of the parameters is about 90%).

Table 1. Coordinates of the permanent stations of the IGS network.

No. of the point	Coordinates in the system ITRF 2005		
	X	Y	Z
BOR1 12205M002	3738358.4247	1148173.7412	5021815.7911
LAMA 12209M001	3524522.8866	1329693.6564	5129846.3546
POTS 14106M003	3800689.6102	882077.4176	5028791.3400

Parameters used for calculations:
- final precise orbits and parameters of the Earth's rotation obtained from IGS,
- absolute models of the phase centres of satellite aerials and receivers, obtained from IGS,
- phase observations L1 and L2,
- horizon mask angle – 10º,
- observation interval - 30 seconds,
- troposphere: one parameter of total zenithal delay per 2 hours (only for check points), mapping function Wet Niell,
- ionosphere model CODE (*Center for Orbit Determination in Europe*),
- determination of indeterminacy: QIF method,
- ultimate coordinates – linear combination L3 (iono-free).

Ultimate coordinates of the reference points were determined by simultaneous alignment of observations from the four days of observations with three permanent stations. The coordinates of reference points in the ITRF 2005 system and their accuracy (the internal accuracy of the BERNESE program) are shown in Table 2. Mean errors of the reference points positions on the plane did not exceed 1.1 mm, whereas the mean error of ellipsoidal altitude for point III reached the maximum value of 1.3 mm.

Table 2. Geodetic coordinates of the reference points in the ITRF 2005 system.

No.	Geodetic coordinates			Mean square errors [m]		
	B [^{0} ' "]	L [^{0} ' "]	h [m]	m_B	m_L	m_h
II	54 21 01.392746	18 36 59.267475	95.4761	0.0011	0.0011	0.0012
III	54 21 39.150453	18 36 50.168854	87.1456	0.0011	0.0011	0.0013
IV	54 21 27.321992	18 38 25.887659	75.5970	0.0011	0.0011	0.0012
V	54 20 36.272276	18 38 06.059764	89.4190	0.0011	0.0011	0.0012

3.2. Determination of the coordinates of the check points

Check points coordinates were determined from the previously calculated reference points coordinates in two 12-hour sessions conducted on 1.12.2006 - 4.12.2006. Cumulative alignment of all the observations was performed (all the independent vectors connecting points for all the sessions of observation) and resulted in the ultimate coordinates of the check points in the ITRF 2005 system.

Short length of vectors connecting reference points and checkpoints make it impossible to determine the troposphere parameters for all the points (due to a high correlation of troposphere parameters on neighbouring points). Consequently, the troposphere parameters were only determined for the check points, while for the reference points the determination results from the previous stage were used.

The parameters taken for calculations:

- **final precise orbits and the parameters of the Earth’s rotation obtained from IGS,**
- **absolute models of phase centres of satellite aerials and receivers, obtained from IGS,**
- **phase observations L1 and L2,**
- **horizon mask angle – 10º,**
- **observation interval - 30 seconds,**
- **troposphere: one parameter of total zenithal delay per 2 hours (only for check points), mapping function Wet Niell,**
- **determination of indeterminacy: wideline/narrowline method (L5/L3),**
- **ultimate coordinates – linear combination L3 (iono-free).**

Ultimate coordinates of the reference points were determined by simultaneous alignment of observations from the two days of observations with four reference points. The coordinates of check points in the ITRF 2005 system and their accuracy (the internal accuracy of the BERNESE program) are shown in Table 3. Mean errors of the reference points positions on the plane did not exceed 1.2 mm in relation to the reference points, whereas the mean error of ellipsoidal altitude for point 7 reached the maximum value of 1.5 mm. The GPS observation results for point 7 will be the least reliable results due to numerous natural obstacles which disrupt the continuity of connection with the observed satellites (Fig.15).

Table 3. Geodetic coordinates of the check points in the ITRF 2005 system.

No.	Geodetic coordinates			Mean square errors [m]		
	B [^{0} ' ”]	L [^{0} ' ”]	h [m]	m_B	m_L	m_h
2	54 20 52.294819	18 38 56.327412	33.6679	0.0012	0.0011	0.0012
3	54 21 09.333647	18 39 00.042431	34.5368	0.0012	0.0011	0.0012
4	54 21 13.986140	18 38 55.109834	36.4580	0.0012	0.0011	0.0012
5	54 21 22.601242	18 39 25.729331	31.9199	0.0012	0.0011	0.0012
6	54 21 13.343384	18 39 27.116075	32.6213	0.0012	0.0011	0.0012
7	54 21 02.752434	18 39 17.572610	33.3178	0.0013	0.0011	0.0015
8	54 20 46.796907	18 39 16.029258	31.8240	0.0012	0.0011	0.0012
9	54 20 32.461856	18 38 48.819756	32.4159	0.0012	0.0011	0.0013
10	54 20 21.988857	18 39 12.481804	30.8309	0.0012	0.0011	0.0012
11	54 20 35.044353	18 39 35.199446	30.4130	0.0012	0.0011	0.0012
12	54 20 42.651477	18 39 50.650593	30.2565	0.0012	0.0011	0.0013
13	54 20 58.456680	18 39 52.381217	30.2006	0.0012	0.0011	0.0012

4. SUMMARY

The results of GPS static measurements, conducted in the first measurement campaign at the reference and check points should be adopted as the values of reference for future observation results. The measurement procedures, developed for the first campaign, should be followed in further measurements.

The measurement equipment (pole for forced centring of a GPS aerial, GPS aerial, GPS receiver) assigned to each point during the first campaign, should be used each time at the check points.
The same calculation procedure should be followed in the analysis of the GPS observation data in future measurement campaigns. If the need to change the calculation procedure is justified, the calculations from previous measurement campaigns should be absolutely redone.

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